held in the hand close to the head. The screw *a*, Fig. 1, must be adjusted to give the best effect.

The other receiving instrument is the most interesting of the two. It consists of a small induction coil used in conjunction with a peculiar sounding-box, as shown in Fig. 3.

Here the line-current is passed to earth through the primary circuit P of the small induction coil, and the induced current is led to the sounding-box. This consists of a flat hollow cylindrical wooden box B, covered by a convoluted face of sheet zinc with two air holes *h h*, perforated in it, this box is attached to a metal axle A, turning in forked iron bearings, insulated from but supported by an iron stand S. By this means the sounding-box can be revolved by the ebony handle E. The zinc face is connected across the empty interior of the box by a wire W to the metal bearings on the other side. One end of the secondary circuit of the induction coil is to be connected to the metal bearing by the terminal *a*, and the other to a short bare wire held in the left hand. On then striking a finger of the hand holding the wire smartly across the zinc face, the proper note is sounded by the box; or, what is more convenient, on turning the box by the insulated handle and keeping the point of the finger rubbing on its face, the note is heard. The rough under side of the finger pressed pretty hard on the bulging part of the face is best. The instant the current is put on by the sending key K, Fig. 1, the dry rasp of the skin on the zinc-surface becomes changed into a musical note.

These "sounders" can be made to receive indifferently a variety of notes. I have under my care at present a telephone with four transmitters tuned to give the four notes of the common chord, and two receivers, which interpret equally well any one of these notes or all together. But sounders are also made in the same way which will emit only one special note, and so are sensible only to the corresponding current. It is by their means that the telephone can be applied to multiplex telegraphy. As many as eight transmitters may be set to interrupt the line current according to the vibrations of eight different tuning-forks, and the resultant current can be made by means of eight special receivers to reproduce the same number of corresponding notes at the distant station. The current is controlled by eight keys at the sending end and sifted by eight sounders at the receiving end, each sounder being sensitive only to those portions of the current affected by its corresponding transmitter. The superimposed effect of the eight keys and transmitters on the line current can all be separately interpreted at the receiving end. Thus eight messages might be transmitted simultaneously along one wire in the same direction. It would seem hitherto, however, that this method of telegraphy by the telephone is inferior to the ordinary methods in point of speed of signalling, and in the length of circuit which can be worked by a given battery power.

J. MUNRO

OUR PERCEPTION OF THE DIRECTION OF A SOURCE OF SOUND[1]

THE practical facility with which we recognise the situation of a sounding body has always been rather a theoretical difficulty. In the case of sight a special optical apparatus is provided whose function it is to modify the uniform excitation of the retina, which a luminous point, wherever situated, would otherwise produce. The mode of action of the crystalline lens of the eye is well understood, and the use of a lens is precisely the device that would at once occur to the mind of an optician ignorant of physiology. The bundle of rays, which would otherwise distribute themselves over the entire retina, and so give no indication of their origin, are made to converge upon a single point, whose excitation is to us the sign of an external object in a certain definite direction. If the luminous object is moved, the fact is at once recognised by the change in the point of excitation.

There is nothing in the ear corresponding to the crystalline lens of the eye, and this not accidentally, so to speak, but by the very nature of the case. The efficient action of a lens depends upon its diameter being at least many times greater than the wave-length of light, and for the purposes of sight there is no difficulty in satisfying this requirement. The wave-length of the rays by which we see is not much more than a ten-thousandth part of the diameter of the pupil of the eye. But when we pass to the case of sound and the ear the relative magnitudes of the corresponding quantities are altogether different. The waves of sound issuing from a man's mouth are about eight feet long, whereas the diameter of the passage of the ear is quite small, and could not well have been made a large multiple of eight feet. It is evident therefore that it is useless to look for anything corresponding to the crystalline lens of the eye, and that our power of telling the origin of a sound must be explained in some different way.

It has long been conjectured that the explanation turns upon the combined use of both ears; though but little seems to have been done hitherto in the way of bringing this view to the test. The observations and calculations now brought forward are very incomplete, but may perhaps help to clear the ground, and will have served their purpose if they induce others to pursue the subject.

The first experiments were made with the view of finding out with what degree of accuracy the direction of a sound could be determined, and for this it was necessary of course that the observer should have no other material for his judgment than that contemplated.

The observer, stationed with his eyes closed in the middle of a lawn on a still evening, was asked to point with the hand in the direction of voices addressed to him by five or six assistants, who continually shifted their position. It was necessary to have several assistants, since it was found that otherwise their steps could be easily followed. The uniform result was that the direction of a human voice used in anything like a natural manner could be told with certainty from a single word, or even vowel to within a few degrees.

But with other sounds the result was different. If the source was on the right or the left of the observer, its position could be told approximately, but it was uncertain whether, for example, a low whistle was in front or behind. This result led us to try a simple sound, such as that given by a fork mounted on a resonance box. It was soon found that whatever might be the case with a truly simple sound, the observer never failed to detect the situation of the fork by the noises accompanying its excitation, whether this was done by striking or by a violin bow. It was therefore necessary to arrange the experiment differently. Two assistants at equal distances and in opposite directions were provided with similar forks and resonators. At a signal given by a fourth, *both* forks were struck, but only *one* was held over its resonator, and the observer was asked to say, without moving his head, which he heard. When the observer was so turned that one fork was immediately in front and the other immediately behind, it was impossible for him to tell which fork was sounding, and if asked to say one or the other, felt that he was only guessing. But on turning a quarter round, so as to have one fork on his right and the other on his left, he could tell without fail, and with full confidence in being correct.

The possibility of distinguishing a voice in front from a voice behind would thus appear to depend on the compound character of the sound in a way that it is not easy to understand, and for which the second ear would be of no advantage. But even in the case of a lateral sound

[1] Abstract of a Communication to the Musical Association, by Lord Rayleigh, F.R.S.

the matter is not free from difficulty, for the difference of intensity with which a lateral sound is perceived by the two ears is not great. The experiment may easily be tried roughly by stopping one ear with the hand, and turning round backwards and forwards while listening to a sound held steadily. Calculation shows, moreover, that the human head, considered as an obstacle to the waves of sound, is scarcely big enough in relation to the wave-length to give a sensible shadow. To throw light on this subject I have calculated the intensity of sound due to a distant source at the various points on the surface of a fixed spherical obstacle. The result depends on the ratio (α) between the circumference of the sphere and the length of the wave. If we call the point on the spherical surface nearest to the source the anterior pole, and the opposite point (where the shadow might be expected to be most intense) the posterior pole, the results on three suppositions as to the relative magnitudes of the sphere and wave-length are given in the following table:—

		Intensity.
$\alpha = 2$	Anterior pole	·690
	Posterior pole	·318
	Equator	·356
$\alpha = 1$	Anterior pole	·503
	Posterior pole	·285
	Equator	·237
$\alpha = \frac{1}{2}$	Anterior pole	·294
	Posterior pole	·260
	Equator	·232

When, for example, the circumference of the sphere is but half the wave-length, the intensity at the posterior pole is only about a tenth part less than at the anterior pole, while the intensity is least of all in a lateral direction. When α is less than $\frac{1}{2}$, the difference of the intensities at the two poles is still less important, amounting to about one per cent. when $\alpha = \frac{1}{4}$.

The value of α depends on the wave-length, which may vary within pretty wide limits, and it might be expected that the facility of distinguishing a lateral sound would diminish when the sound is grave. Experiments were accordingly tried with forks of a frequency of 128, but no greater difficulty was experienced than with forks of a frequency of 256, except such as might be attributed to the inferior loudness of the former. According to calculation the difference of intensity would here be too small to account for the power of discrimination.

PROF. HUXLEY'S LECTURES ON THE EVIDENCE AS TO THE ORIGIN OF EXISTING VERTEBRATE ANIMALS[1]

VI.

IN the highest group of Vertebrates, the Mammalia, the perfection of animal structure is attained. It will hardly be necessary, indeed it will be impossible, in the time at our disposal, to give the general characters of the group, but our purpose will be answered as well by devoting a short time to considering the peculiarities of a single well-known animal, the evidence as to the origin of which approaches precision.

The horse is one of the most specialised and peculiar of animals, its whole structure being so modified as to make it the most perfect living locomotive engine which it is possible to imagine. The chief points in which its structure is modified to bring about this specialisation, and in which, therefore, it differs most markedly from other mammals, we must now consider.

In the skull the orbit is completely closed behind by bone, a character found only in the most modified mammals. The teeth have a very peculiar character. There are, first of all, in the front part of each jaw, six long curved incisors or cutting teeth, which present a singular dark mark on their biting surfaces, caused by the filling in of a deep groove on the crown of each tooth, by the substances on which the animal feeds. After the incisors, comes on both sides of each jaw a considerable toothless interval, or *diastema*, and then six large grinding teeth, or molars and premolars. In the young horse a small extra premolar is found to exist at the hinder end of the diastema, so that there are, in reality, seven grinders on each side above and below; furthermore, the male horse has a tusk-like tooth, or canine, in the front part of the diastema immediately following the last incisor. Thus, the horse has, on each side of each jaw, three incisors, one canine, and seven grinders, making a total of forty-four teeth.

The grinding surfaces of the molars and premolars are very curious. In the upper jaw, each tooth is marked by four crescentic elevations, concave externally, the inner pair having each a curious folded mass connected with it. These projecting marks are formed of dentine and enamel, and, consequently, wear away more slowly than the intervening portions of the tooth, which are composed of cement. The lower grinders are marked with two crescents and two accessory masses, but the crescents are convex externally, and, consequently, when the opposite teeth bite together, the elevations do not correspond at any point. In this way a very perfect grinding surface is obtained. The teeth are of great length, and go on growing for a long time, only forming roots in old animals. All these points contribute to the perfection of the horse as a machine, by rendering the mastication of the food, and its consequent preparation for digestion in the stomach, as rapid and complete a process as possible.

It is, however, in the limbs that the most striking deviation from the typical mammalian structure is seen, the most singular modifications having taken place to produce a set of long, jointed levers, combining great strength with the utmost possible spring and lightness.

The humerus is a comparatively short bone inclined backwards: the radius is stout and strong, but the ulna seems to be reduced to its upper end—the olecranon or elbow; as a matter of fact, however, its distal end is left, fused to the radius, but the middle part has entirely disappeared: the carpus or wrist—the so-called "knee" of the horse—is followed by a long "cannon-bone," attached to the sides of which are two small "splint-bones"; the three together evidently represent the metacarpus, and it can be readily shown that the great cannon-bone is the metacarpal of the third finger, the splint-bones those of the second and fourth. The splint-bones taper away at their lower ends and have no phalanges attached to them, but the cannon-bone is followed by the usual three phalanges, the last of which, the "coffin-bone," is ensheathed by the great nail or hoof.

The femur, like the humerus, is a short bone, but is directed forwards; the tibia turns backwards, and has the upper end of the rudimentary fibula attached to its outer angle. The latter bone, like the ulna, has disappeared altogether as to its middle portion, and its distal end is firmly united to the tibia. The foot has the same structure as the corresponding part in the fore-limb—a great cannon-bone, the third metatarsal; two splints, the second and fourth; and the three phalanges of the third digit, the last of which bears a hoof.

Thus, in both fore and hind limb one toe is selected, becomes greatly modified and enlarged at the expense of the others, and forms a great lever, which, in combination with the levers constituted by the upper and middle divisions of the limb, forms a sort of double C-spring arrangement, and thus gives to the horse its wonderful galloping power.

In the river-beds of the Quaternary age—a time when England formed part of the Continent of Europe—

[1] A course of six lectures to working men, delivered in the theatre of the Royal School of Mines. Lecture VI., April 3. Continued from vol. xiii. p. 516.